IK4 IDEKO Research Alliance

Thermal error compensation for large heavy duty milling-boring machines

Gorka Aguirre, Aitor Pérez de Nanclares, Harkaitz Urreta
gaguirre@ideko.es

euspen SIG Thermal Issues 2014
Zurich, CH

IK4-IDEKO

IK4 IDEKO Research Alliance
R&D Center
Manufacturing & Production technologies
100 researchers, 20PhD
8M€

IK4 Research Alliance
9 R&D Centers
1.400 researchers
300PhD
100M€
150 patents
500 publications

DANOBATGROUP
Machine-Tool Building
Global Customized Solutions
Market-oriented Innovation
Leading-edge Technology
Workforce: 1.200
Turn-over: 200M€

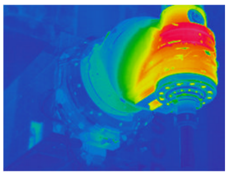
Outline

Large heavy duty milling-boring machines

Thermal error management

Thermal Error Compensation System

General considerations



Large heavy duty milling-boring machines

SORALUCE

Applications
- Heavy duty milling and boring
- Large parts, high precision
- Oil&gas, wind energy, aeronautics, etc.

Large machines
- Vertical travel up to 8m
- Longitudinal travel up to 60m
- Multiple spindle/quills with automatic changer

Main thermal issues
- Heavy duty: high heat generation, spindles can rate up to 88kW
- Large machine: error amplification with increasing workspace

Thermal error management strategies

Temperature control
Minimize temperature variations in the machine

↓

Design for thermal error reduction
Minimize errors at TCP generated by temperature changes

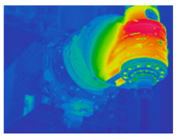
↓

Thermal error compensation
Compensate remaining errors at TCP

Temperature control

Minimize temperature variations in the machine

Heat sources
- Bearings around spindle area
- Ambient temperature, not controlled
- Hydrostatic bearings
- Hot chip falling against machine
- Motors



Cooling units
- Minimize temperature variations, but limited by high required power.
- Dangerous, cooling circuits can be a disturbance source
- Might be too expensive

Design for thermal error reduction

Minimize errors at TCP generated by thermal changes in the machine

Application of precision design principles
- Machine design is focused on stiffness
- Precision is important, but it comes next

Focus on avoiding bending errors
- Linear errors are 'easy' to compensate
- Bending errors are more difficult to compensate at TCP
- Bending errors change tool orientation

Thermal error compensation

Estimate and compensate thermal errors during machine operation

Thermoelastic machine model
- Relates thermal error with temperature field, spindle speed, position in workspace
- Can be based on simulations (FEM) and/or measured data

Implementation
- Experiments/simulations to characterize model
- Simulation model running on CNC/PLC

Impact
- Low cost solution, big improvements are possible
- Risk of lack of robustness

Thermal Compensation System

Main objectives

Robust and effective compensation method:
- Improve machine accuracy, never make it worse

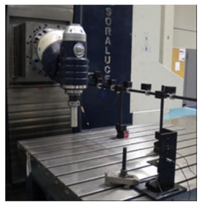
Minimize machine occupation time:
- Fast machine characterization method
- Multiple heads, one 8h shift per spindle head and quill

Simple to implement
- By machine operator
- Automate the process

Flexible
- Compatible with main CNC systems
- Full range of machines/spindles/quills

Experimental setup

Software in external laptop
- Data acquisition from CNC/PLC and displacement sensors
- Generate movement program for CNC
- Automatic model fitting
- Automatic generation of compensation tables



Hardware
- Several measuring points within workspace
  - RAM and quill positions
  - Spindle orientations
- Thermally stable measurement targets

Implementation in machine control

Variety of controllers


Heindenhain


Siemens Sinumerik

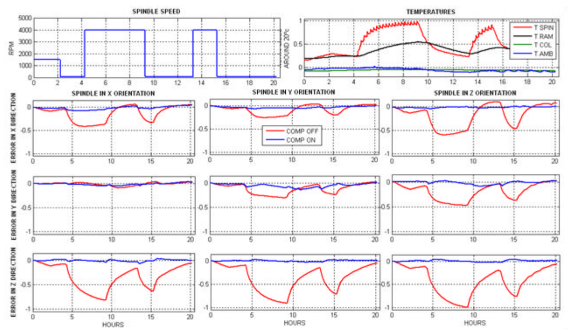

Fanuc


Fagor Automation

Data acquisition
- Temperature from embedded sensors
- Machine axis positions

Compensation in CNC/PLC
- Application on CNC PC
- Embedded code in PLC

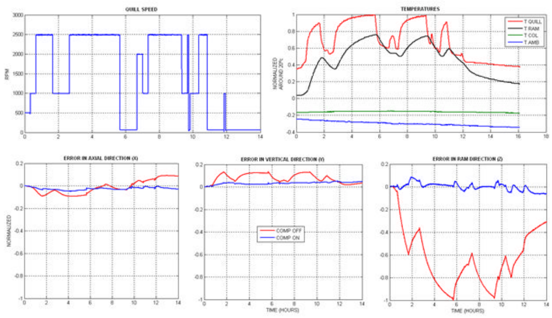
Compensation results: spindle head



All results are normalized to the maximum measured value

IK4 IDEKO
Research Alliance

Compensation results: quill



All results are normalized to the maximum measured value

IK4 IDEKO
Research Alliance

General considerations

Do not be too ambitious, focus on dominant errors:
- Smaller effects are more difficult to characterize, and
- They might affect robustness

Compensation model structure
- The simpler the better, improve sensor location before adding complexity
- Temperatures and machine position as only inputs to the model

FE can be useful
- Improve design and cooling elements (Minimize bending deformations!)
- Find optimal sensor location (structural elements, near heat source, near linear scales)
- Not for compensation, experiments are needed if high precision is required

IK4 IDEKO
Research Alliance

General considerations

Careful with **cooling systems**
- Keep machine temperature constant, not at 20ºC
- Damp transient effects

Keep in mind **industrial feasibility**
- Minimize machine occupation time
- Simple procedure to be implemented by operators
- Be aware of control requirements/limitations

Special applications with extreme requirements
- When possible, re-think the manufacturing steps (CAM)
- Add many more sensors, use some math tricks (e.g. POD) to find best correlating ones
- Take time to properly characterize the effect of ambient temperature

Thank you!